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THE CHOICE OF ALLOYS FOR WATER WORK DESIGN

By Horace Carpenter

In the design of water works equipment, the engineer makes use of the various noncorrosive metallic alloys only to such extent as the inaccessibility of the equipment or the danger of interruption of service render it imperative to use some material other than iron or steel. Consequently, the amount of such material has, in the past, been slight in comparison with the magnitude of other materials entering into such work, and the engineer has been content to accept, largely without question, such alloys as were commercially available, without any extensive study of the applicability of any particular alloy to the purpose for which it was to be used.

The increasing magnitude of such work, however, makes the proper selection of alloys of increasing importance to the engineer, and it is the purpose of this paper, not to attempt to set forth in detail any fixed rules to govern selection, but to open the way for discussion and to bring forth the results of the study of others who have been able to make a more detailed study of the matter than has the writer.

Alloys are used for water works construction in two forms:

1. *Castings.* In this form they appear in parts the shape or purpose of which is such that it is possible for the material to pass directly from the foundry to the point of application, with only such intervening fabrication as tends in no way to alter the structure of the material, or to change its physical characteristics.

2. *Bars or tubes.* In this form these alloys must, in nearly all cases, be so fabricated after leaving the foundry that their structure and physical characteristics are materially changed. This fabrication consists of forging, rolling, extruding or drawing.

The ideal alloy must possess three characteristics which, in the order of their relative importance, may be classed as follows:

1. The material must be able to withstand, for an indefinite period, the disintegrating action of the elements with which it is to come in contact, this action taking the form of corrosion, erosion, or electrolysis, either or all of which may be present.

2. The material must be of such structure that it will successfully withstand disintegration due to the failure of its component parts to retain their original relation one to another, and must be free from internal stress which will produce progressive failure entirely independent of any exterior agency. This latter requirement implies a composition capable of successful fabrication under existing commercial conditions.

3. Since the materials are comparatively costly, it is desirable that the physical characteristics be as high as practicable in order that the desired result may be obtained at the least expense.

It is desirable to bring to your attention four of the classes of alloys, and to consider briefly their ability to fulfill the requirements of the above specifications, as follows:

The bronzes, or copper-tin alloys.
The brasses, or copper-zinc alloys.
The copper-nickel alloys, and
The nickel-steel alloys.

The bronzes are of ancient origin and, in slightly varying composition, have been used for many centuries. The most commonly accepted composition today appears to be that of the so-called "naval bronze," consisting of 88 per cent copper, 10 per cent tin, and 2 per cent zinc.

Castings of this alloy fulfill the requirements of the foregoing specifications in a very satisfactory manner. They are noncorrosive in the presence of nearly, if not all, the elements with which they are ordinarily brought in contact, they are easily obtainable, of a homogeneous character under ordinary commercial conditions, are stable and constant in physical characteristics, and the material is one that works well in the ordinary machinery operations.

Their physical characteristics are sufficiently high so that apparatus does not need to be unwieldy or unduly heavy in design to obtain the requisite strength under any ordinary conditions. A tensile strength of 30,000 pounds per square inch, a yield point of 15,000 pounds and an elongation of 15 per cent in two inches can easily be obtained.

Rigid adherence to the composition as given above does not appear essential. The copper may be reduced to 85 per cent, with a corresponding increase in the zinc content, or with a corresponding addition of lead without materially changing the ability of the resulting casting to resist corrosion and without material change in its physical characteristics. In fact, in the presence of sulphur the addition of lead appears to aid the resistance to corrosion.

Where the material is to be used as a bearing metal, as in the seats of large gates, a considerable variation in the composition is desirable. The United States Reclamation Service has worked out for this purpose two alloys to be used in opposition to one another, as follows:

82.8 per cent copper, 4.8 per cent tin, 4.4 per cent zinc, and 8 per cent lead.

82.7 per cent copper, 7.1 per cent tin, 5.3 per cent zinc, and 4.9 per cent lead.

Experiments by the writer, while indicating the impracticability of attempting to confine the composition as closely as indicated, demonstrate that alloys of this nature containing about 5 per cent lead in one and 8 per cent in the other, with corresponding differences in the tin content, were very satisfactory for the purpose.

Alloys of the above nature may be used for castings only as their high tin content makes it impossible to hammer, forge, roll or draw them successfully, so that, where rods or tubes are required, the content of tin must not exceed 2 per cent, and most manufacturers hold to a maximum of 1½ per cent.

Where conditions of design require greater physical characteristics than shown by the bronzes, or where forged, rolled or drawn forms are required, the engineer commonly resorts to the brasses, of which there are an endless variety, many of them of little value, but of which a number have proven highly satisfactory.

For castings of this character, manganese bronze has been very generally accepted and has given very satisfactory service. A characteristic casting of this material shows a composition of about 56 per cent copper, 40 per cent zinc, 1 per cent tin, 1.27 per cent iron, and 1.8 per cent manganese. It will be noted that the manganese content is small, and it does not appear essential that the analysis of the completed casting show any such content, the manganese being introduced in the form of the ferrous-oxide to act as a flux, and any residue being due to an overdose of the flux, and such residue should not exceed 2 per cent. Such castings, properly made, can be relied upon to show a tensile strength of 65,000 pounds, a yield point of 35,000, and an elongation of 20 per cent in 2 inches. Certain manufacturers use vanadium in the place of manganese, and the resulting castings are of the same general character as manganese bronze. Castings of this material where purchased in small quantities are generally somewhat more expensive than those made of the bronzes referred to above, and it is the general experience that founders unused to the casting of manganese bronze experience considerable difficulty in obtaining satisfactory results. Where the quantity, however, to be used on a job is sufficient to appeal to founders experienced in handling the material, most excellent castings can be obtained at a price generally from 10 to 12 per cent less than corresponding castings of tin bronze.

Forgings, rods and bars of these alloys show very satisfactory noncorrosive properties and physical characteristics considerably greater than the cast material, the exact amount depending on the size and manner of fabrication, and would appear at first glance to be ideal substitutes for similar steel products. Unfortunately, however, the demand for such rods and bars is of such recent origin that the art of fabrication does not seem to have advanced to a point where the product can be guaranteed against failure by disintegration, or by breaking or cracking without apparent cause. These failures in many instances have not manifested themselves until some months after the material has been fabricated and has passed a most rigid inspection, and have been entirely independent of any load thrown on the material. While no satisfactory solution of the causes of, and no remedy for such failures, have as yet been found, it does appear that the same are caused rather by the methods employed in rolling or drawing than by the composition of the material itself. It would, therefore, appear wise to exercise considerable conservatism in the selection of such rods, until the manufacturers have further perfected themselves, and have solved the various problems of temperature and rolling methods, and to use in their stead some of the brasses which have been manufactured for a sufficient length of time so that the engineer can feel comparative security in their use. Among these there appear Muntz metal, an alloy of 60 per cent copper and 40 per cent zinc, which in the larger sizes of rods can be depended upon to show a tensile strength of at least 40,000 pounds, and Tobin bronze with a tensile strength of 55,000 pounds, which together with other closely allied alloys are readily available.

Comparatively recently, one of our largest manufacturers of rods has produced an alloy containing about 57½ per cent copper, 40 per cent tin, ½ per cent lead, ½ per cent iron, and 1½ per cent nickel, which possesses high noncorrosive properties, together with physical characteristics equal to or slightly superior to Muntz metal. This material is produced in bars and rods.

Tubes made of an alloy of 86 per cent copper and 14 per cent tin are extensively used in the navy in condensers, where they come in contact with salt water.

The most prominent copper-nickel alloy today appears to be Monel metal, a natural alloy containing about 60 per cent nickel, 36½ per cent copper, and 3½ per cent iron. This material has been very successfully used both in the form of castings and rods for large and small work. Its physical characteristics are at least 65,000 pounds ultimate, 32,000 pounds yield, and 25 per cent elongation for castings, with the ultimate and yield points at least 10 per cent higher for rolled rods. Noncorrosive tests indicate that it is not acted upon by either the acids or alkalies as found in construction work. It has been somewhat extensively used for propellers for battleships, both by this country and by foreign countries. It is also used by many valve manufacturers as a seat metal for valves, for use with high pressure and superheated steam. It is also used in the form of forgings for valve stems for high pressure steam and water valves.

This material has not been in use for a sufficient length of time to determine its noncorrosive qualities under all circumstances, but every indication points to its entire acceptability. It is a comparatively costly material, probably costing in its various forms about 50 per cent more than the corresponding brass or bronze material, but its greater physical characteristics in many cases make this increase more apparent than real. It appears to require considerable skill on the part of the founder to obtain sound castings of Monel metal, and the unsuccessful attempts of some such have prejudiced many against its use.

The value of nickel-steel alloys for members under tension, as valve stems, has not received sufficient recognition by the water works engineer.

While unquestionably not possessing the noncorrosive properties of the brasses or bronzes, a proper steel alloyed with from 20 to 25 per cent of nickel does possess such properties far in excess of ordinary carbon steels and combines with this property physical characteristics such that it should demand the careful consideration of the engineer.

In 1905 the Department of Water Supply, Gas and Electricity of New York City specified for valve stems a nickel steel to contain not more than 0.05 per cent phosphorus or sulphur, between 0.21 per cent and 0.41 per cent carbon, and between 21 per cent and 24 per cent nickel and to have a tensile strength of at least 80,000 pounds, yield point of 40,000 and an elongation of 22 per cent.

One of these stems when examined after five years' service showed no indication of corrosion of that part immersed in water, and only slight pitting of that part exposed to air.

There appears to be very little data available showing the effect of various corrosive substances on alloys. Unquestionably many of the manufacturers of such materials have experimented to a considerable extent on such material, but there appears to have been, in the past at least, a dislike on their part to make public the results which they may have obtained. There are appended to this paper a few results of comparative tests that have come to the attention of the writer and which, while by no means complete or conclusive, may be of some assistance in the selection of noncorrosive alloys.

THE CORROSIVE EFFECT OF MOIST EARTH ON ALLOYS AND STEEL

Six test pieces were imbedded in a box of rich earth, which was kept moist with water and occasional additions of ½ per cent solutions of chlorides of sodium and magnesium. The weighed specimens, consisting of rods 15.2 cm. long by 1.2 cm. diameter, presented about the same area to the corrosive influences in the soil. After having been subjected to the conditions provided for a period of six months, the specimens were taken out, washed, dried and reweighed. The loss in weight represented the amount of corrosion in each case.

SAMPLE	ORIGINAL WEIGHT	LOSS IN WEIGHT	PER CENT LOSS
	grams	*grams*	
Manganese bronze	171.87	0.16	0.09
Tobin bronze	162.11	0.19	0.11
Monel metal	160.76	0.19	0.12
Manganese bronze	161.65	0.19	0.12
Muntz metal	163.85	0.55	0.33
Steel	139.58	1.45	1.04

All the specimens showed the effect of more or less oxidation on the surface, the Monel metal presenting the least change in appearance as a result of corrosive action.

CORROSION TESTS ON CAST MANGANESE BRONZE AND CAST MONEL METAL

Relative corrosibility, as indicated by resistance to solvent action of acid solutions and acid solutions containing dissolved salts.

Small specimens of each metal about the same size and weight (35 grams, with length and diameter of 1.2 inch and 0.5 inch) were subjected to the action of 100 cc. of the solutions, in covered glass beakers, for ten days, at room temperature. The specimens were then removed from the solutions, washed, wiped, dried, and reweighed, the percentage loss in weight indicating the degree or extent of corrosion.

Corrosive or solvent action of 10 per cent solution of sulphuric acid

	Loss per cent
Monel metal	0.096
Manganese bronze	0.018

Corrosive action of 10 per cent sulphuric acid, containing iron sulphate

Monel metal	0.32
Manganese bronze	0.37

Corrosive action of 20 per cent solution of hydrochloric acid

Monel metal	0.21
Manganese bronze	7.34

Corrosive action of 20 per cent hydrochloric acid solution with common salt in solution.

Monel metal	0.31
Manganese bronze	1.64

Comparative Corrosion List of Various Alloys

Duration of test 6 months

	COPPER	ZINC	LEAD	TIN	IRON	NICKEL
Alloy A	57.7	40.1	0.44		0.46	1.3
Alloy B	62.6	36.1	0.20	1.1		
Alloy C	62.7	35.1	2.20			
Alloy D	61.0	38.1	0.20	0.5		
Alloy E	89.0			11.0		
Alloy F	54.3	27.0	0.10		0.10	18.3

Solution No. 1	Sea water.
Solution No. 2	Ammonium chloride, 20 per cent solution.
Solution No. 3	Ferrous sulphate, 10 per cent solution.
Solution No. 4	Sulphuric acid, 10 per cent commercial.
Solution No. 5	Swamp water,
Solution No. 6	Sodium hydroxide, 10 per cent solution.

ALLOY	SOLUTION NO. 1		SOLUTION NO. 2		SOLUTION NO. 3	
	Loss in weight, grams per sq. in. of surface	Appearance	Loss in weight, grams per sq. in. of surface	Appearance	Loss in weight, grams per sq. in. of surface	Appearance
A........	0.0184	smooth sound	0.3790	rough sound	0.085	smooth sound
B........	0.1364	smooth sound	4.2460	pitted, disintegrated	0.091	smooth sound
C........	0.1590	etched sound	3.5980	very rough disintegrated	0.092	etched sound
D........	0.1390	etched sound	5.4530	very rough disintegrated	0.093	smooth sound
E........	0.1700	etched sound	6.8080	very rough	0.089	etched sound
F........	0.0660	rough lengthwise cracks	0.5611	rough deeply pitted	0.041	etched lengthwise cracks

ALLOY	SOLUTION NO. 4		SOLUTION NO. 5		SOLUTION NO. 6	
	Loss in weight	Appearance	Loss in weight	Appearance	Loss in weight	Appearance
A........	0.102	etched sound	0.0030	smooth sound	0.0270	smooth lengthwise cracks
B........	0.110	etched sound	0.0014	smooth sound	0.0300	smooth sound
C........	0.132	etched sound	0.0043	smooth sound	0.0180	smooth sound
D........	0.107	smooth sound	0.0117	smooth sound	0.0270	smooth sound
E........	0.147	etched sound	0.0020	smooth sound	0.0320	corroded sound
F........	0.063	etched sound			0.0045	clean sound